Properties of particle production at large transverse momentum in Au+Au and Cu+Cu collisions at RHIC

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Abstract.

We present the incident energy and system size dependence of the $p_{\rm T}$ spectra for $\pi^{\pm}$, p, and $\bar{p}$ using Au+Au and Cu+Cu collisions at $\sqrt{s_{\rm NN}}$ = 62.4 and 200 GeV in STAR experiment at RHIC. Through these measurements in the $p_{\rm T}$ range of 0.2 $< p_{\rm T} <$ 10 GeV/c we conduct a systematic study of the beam energy, system size and particle species dependence of nuclear modification factor and address specific predictions from the quark coalescence models regarding beam energy dependence of baryon enhancement in the intermediate $p_{\rm T}$ ($2 < p_{\rm T} < 6$ GeV/c) region.

1. Introduction

A detailed study of beam energy ($\sqrt{s_{\rm NN}}$), transverse momentum ($p_{\rm T}$) and system size dependence of identified hadron production will provide the necessary data to understand the mechanism of energy loss, put constraints on parameters in energy loss model calculations like initial gluon density [1] and life time of dense matter [2], and will also help in probing the non-Abelian features of color charge dependence of parton energy loss [3, 4]. The energy dependence of baryon to meson ratio at intermediate $p_{\rm T}$ region of 2 - 6 GeV/c will address the specific prediction from the quark coalescence models of a higher baryon to meson ratio at $\sqrt{s_{\rm NN}}$ = 62.4 GeV compared to $\sqrt{s_{\rm NN}}$ = 200 GeV [5]. At high $p_{\rm T}$ ($>$ 6 GeV/c) the p/π ratio can provide information on quark and gluon jet conversions in the medium formed in heavy ion collisions [6].

2. Experiment and Analysis

The data presented here are obtained from the Time Projection Chamber (TPC) and the Time-Of-Flight (TOF) detector in the STAR experiment [7] at RHIC in the year 2004. Measurements of the ionization energy loss of charged tracks in the TPC gas under a magnetic field of 0.5 Tesla are used to identify $\pi^{\pm}$, p and $\bar{p}$ within $\mid \eta \mid < 0.5$

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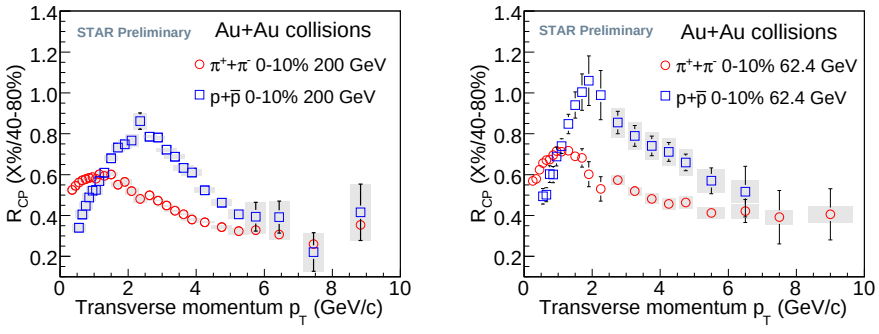

Figure 1. $R_{\rm CP}$ for $\pi^+ + \pi^-$ and $p+\bar{p}$ in Au+Au collisions at $\sqrt{s_{\rm NN}} = 200$ (left panel) and 62.4 GeV (right panel). The error bars are statistical, the shaded bands are systematic errors. There is an additional error of about 10% not shown in the figure due to uncertainty in $N_{\rm bin}$ calculations.

and full azimuth, for $p_{\rm T} \leq 1.1$ GeV/c and $2.5 \leq p_{\rm T} \leq 10$ GeV/c. The data from TOF provides particle identification up to $p_T \sim 3$ GeV/c for pions and protons in $-1 < \eta < 0$ in pseudorapidity and $\pi/30$ rad in azimuth. Weak-decay feed-down (e.g. $K^0_S \rightarrow \pi^+\pi^-$) to the pion spectra was subtracted from the results presented. Inclusive p and $\bar{p}$ production include all of the hyperon feed-downs to reflect total baryon production. Systematic errors for the TOF measurements are similar at both energies and are around 8% [8]. The total systematic errors on charged pion yields at both energies and collision systems are estimated to be $\lesssim$ 15% and those for proton and anti-protons to be $\lesssim$ 26% over the entire $p_{\rm T}$ range studied [8].

3. Results

3.1. Nuclear Modification Factor

The nuclear modification factor ($R_{\rm CP}$) is defined as, $R_{\rm CP}(p_{\rm T}) = \frac{\langle N^{\rm peri}_{\rm bin}\rangle d^2N_{\rm cent}/dydp_{\rm T}}{\langle N^{\rm cent}_{\rm bin}\rangle d^2N_{\rm peri}/dydp_{\rm T}}$, where $\langle N_{\rm bin}\rangle$ is the average number of binary nucleon-nucleon collisions per event. Figure 1 shows the beam energy and $p_{\rm T}$ dependence of $R_{\rm CP}$ for $\pi^+ + \pi^-$ and $p+\bar{p}$ in Au+Au collisions. There is a distinct difference in $p_{\rm T}$ dependence of $R_{\rm CP}$ for charged pions and protons+anti-protons observed at both energies. The $R_{\rm CP}$ values at $\sqrt{s_{\rm NN}} =$ 62.4 GeV is higher than for $\sqrt{s_{\rm NN}} = 200$ GeV for $p_{\rm T} < 7$ GeV/c, beyond this $p_{\rm T}$ they seem to approach each other. This may indicate a similar energy loss of quarks and gluons in the medium formed in high energy heavy ion collisions. Considering a similar energy dependence of parton energy loss with a smaller initial gluon density at lower energy, one may expect the $R_{\rm CP}$ to approach each other at high $p_{\rm T}$ due to a steeper initial jet spectra at 62.4 GeV. At high $p_{\rm T}$ a similar value of $R_{\rm CP}$ for $p+\bar{p}$ and $\pi^+ + \pi^-$ is observed at both energies

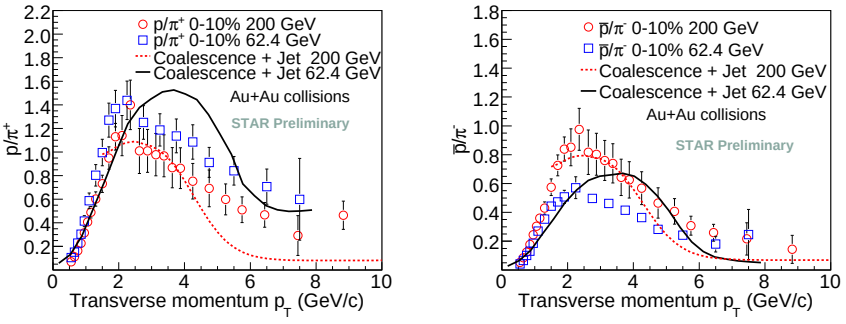

Figure 2. p/π^+ (left panel) and $\bar{p}/\pi^-$ (right panel) for 0-10% Au+Au collisions at $\sqrt{s_{\rm NN}}$ = 200 and 62.4 GeV. The error bars are systematic and statistical errors added in quadrature. Data are compared to model calculations based on coalescence and jet fragmentation in Refs. [5, 9].

3.2. Baryon to Meson Ratio

Figure 2 shows the p/π^+ and $\bar{p}/\pi^-$ ratios for Au+Au collisions at $\sqrt{s_{\rm NN}}$ = 200 and 62.4 GeV. The experimental results are compared to model calculations based on coalescence and jet fragmentation [5, 9]. The p/π^+ ratio for Au+Au collisions at $\sqrt{s_{\rm NN}}$ = 62.4 GeV is higher than corresponding values at $\sqrt{s_{\rm NN}}$ = 200 GeV in the intermediate $p_{\rm T}$ range. However, the case for $\bar{p}/\pi^-$ ratio is reversed. This trend in energy dependence of the baryon-to-meson ratios as a function of $p_{\rm T}$ are consistent with models having quark coalescence as the dominant mechanism of particle production at intermediate $p_{\rm T}$ [5]. Comparison of the p/π^+ and $\bar{p}/\pi^-$ ratios to predictions from model shows they qualitatively predicts the general trend of energy and $p_{\rm T}$ dependence correctly. However there is a lack quantitative agreement.

3.3. System size dependence

Figure 3 shows the comparison $\bar{p}/p$, p/π^+, $\bar{p}/\pi^-$ and $R_{AA}^{\pi^++\pi^-}$ $(= \frac{d^2N_{\rm AuAu}/dydp_{\rm T}}{(\langle N_{\rm bin}\rangle/\sigma_{\rm pp}^{\rm inel})\, d^2\sigma_{\rm pp}/dydp_{\rm T}})$ for Au+Au and Cu+Cu collisions having similar $N_{\rm part}$ and $N_{\rm bin}$ at $\sqrt{s_{\rm NN}}$ = 200 and 62.4 GeV. For the $R_{AA}^{\pi^++\pi^-}$ at $\sqrt{s_{\rm NN}}$ = 62.4 GeV, the $\sigma_{\rm pp}^{\rm inel}$ is taken to be 36 mb and the $p+p$ data are from the parametrization available from ISR data in the Ref.[10]. We observe for similar $N_{\rm part}$ and/or $N_{\rm bin}$ at a given beam energy, the above observables at high $p_{\rm T}$ have similar values in Au+Au and Cu+Cu collisions.

4. Summary

We have presented a study of the energy dependence of the $\pi^{\pm}$, p and $\bar{p}$ production at high $p_{\rm T}$ from Au+Au and Cu+Cu collisions at $\sqrt{s_{\rm NN}}$ = 62.4 and 200 GeV. There is a distinct difference in $p_{\rm T}$ dependence of R_{CP} for charged pions and protons+anti-protons observed at both energies. However at higher $p_{\rm T}$ the values of $R_{\rm CP}$ for baryons and mesons at both energies are similar. This together with a recent observation of a

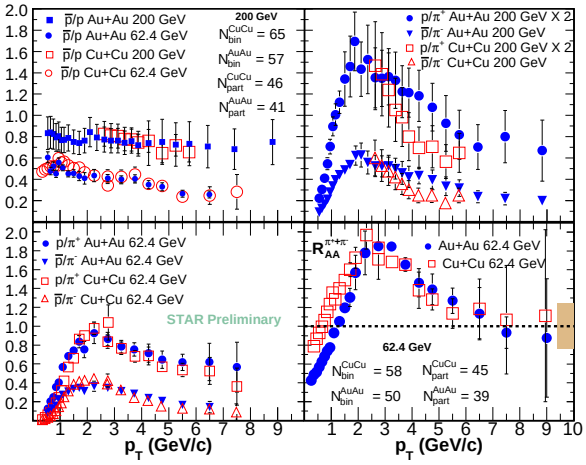

Figure 3. Comparison of $\bar{p}/p$ (top left panel) , p/π^+, $\bar{p}/\pi^-$ (top right and bottom left panels) and $R_{AA}^{\pi^++\pi^-}$ (bottom right panel) for Au+Au and Cu+Cu collisions having similar number of participating nucleons ($N_{\rm part}$) and number of binary collisions ($N_{\rm bin}$) at $\sqrt{s_{\rm NN}} = 200$ and 62.4 GeV. The error bars are systematic and statistical errors added in quadrature. The shaded band in the panel showing R_{AA} is the uncertainty due to $N_{\rm bin}$ calculations. R_{AA} has an additional 25% uncertainty due to the parametrization used for p+p data at $\sqrt{s_{\rm NN}} = 62.4$ GeV [10].

comparable $\bar{p}/\pi^-$ ratio in 200 GeV Au+Au collisions and d+Au collisions [4, 8] at high $p_{\rm T}$ provides necessary data to understand role of interaction of quarks, gluons in the medium and their energy loss mechanism. The p/π^+ ratio for Au+Au collisions at $\sqrt{s_{\rm NN}}$ = 62.4 GeV is higher than corresponding values at $\sqrt{s_{\rm NN}} = 200$ GeV in the intermediate $p_{\rm T}$ range. The case for $\bar{p}/\pi^-$ ratio is reversed. Such an energy is qualitatively consistent with models where quark coalescence is the dominant mechanism of particle production at intermediate $p_{\rm T}$. However there are quantitative disagreements of data with such models. We also observe similar values of high $p_{\rm T}$ particle ratios and R_{AA} in Au+Au and Cu+Cu collisions for collisions with similar $N_{\rm part}$ and/or $N_{\rm bin}$.

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